LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

Arthur H. Rosenfeld, Ph.D.
Ronnen Levinson, Ph.D.
Melvin Pomerantz, Ph.D.

FriendsofBerkeleyLab.lbl.gov

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

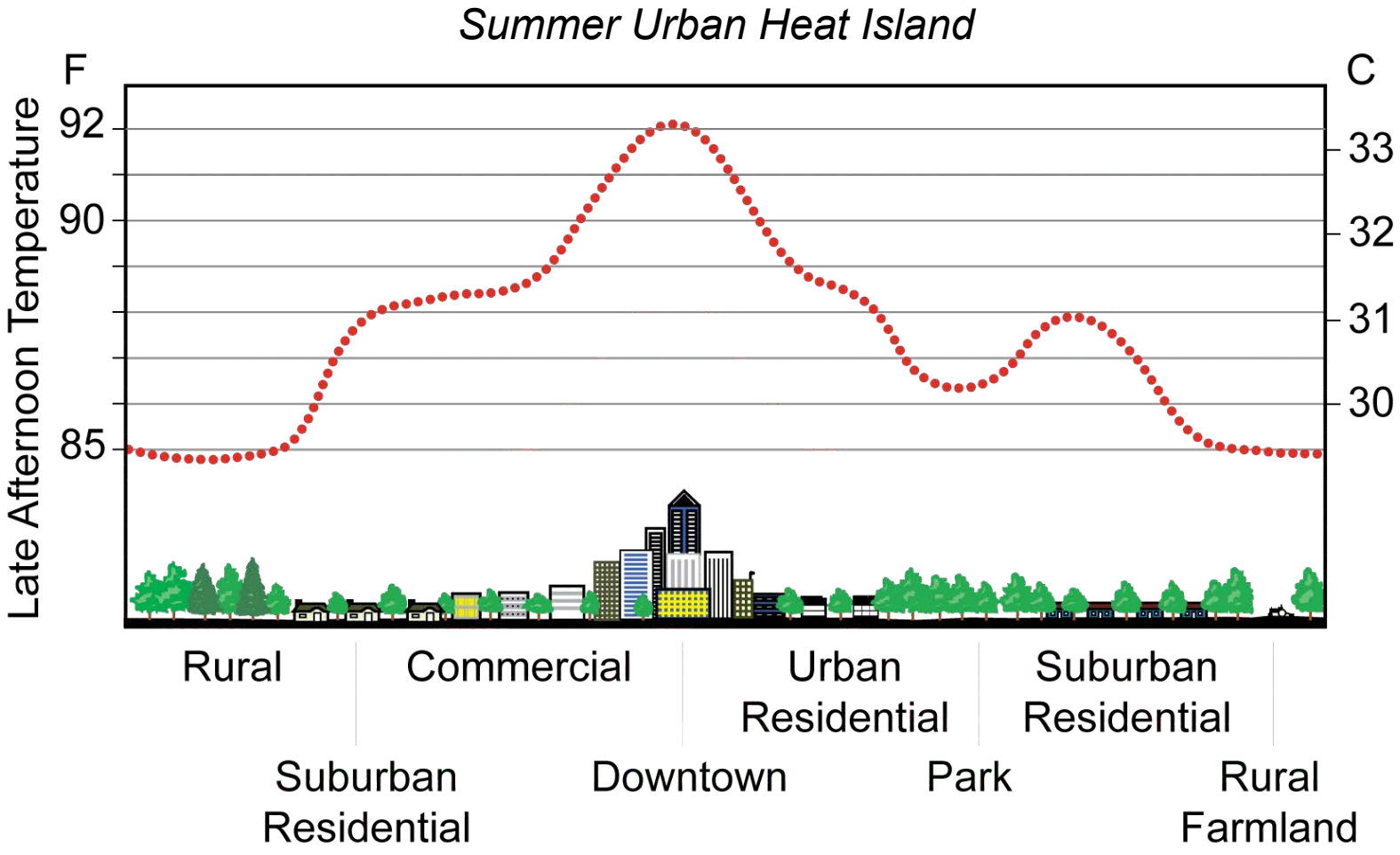
COOL CITIES, COOL PLANET

Melvin Pomerantz, Ph.D.

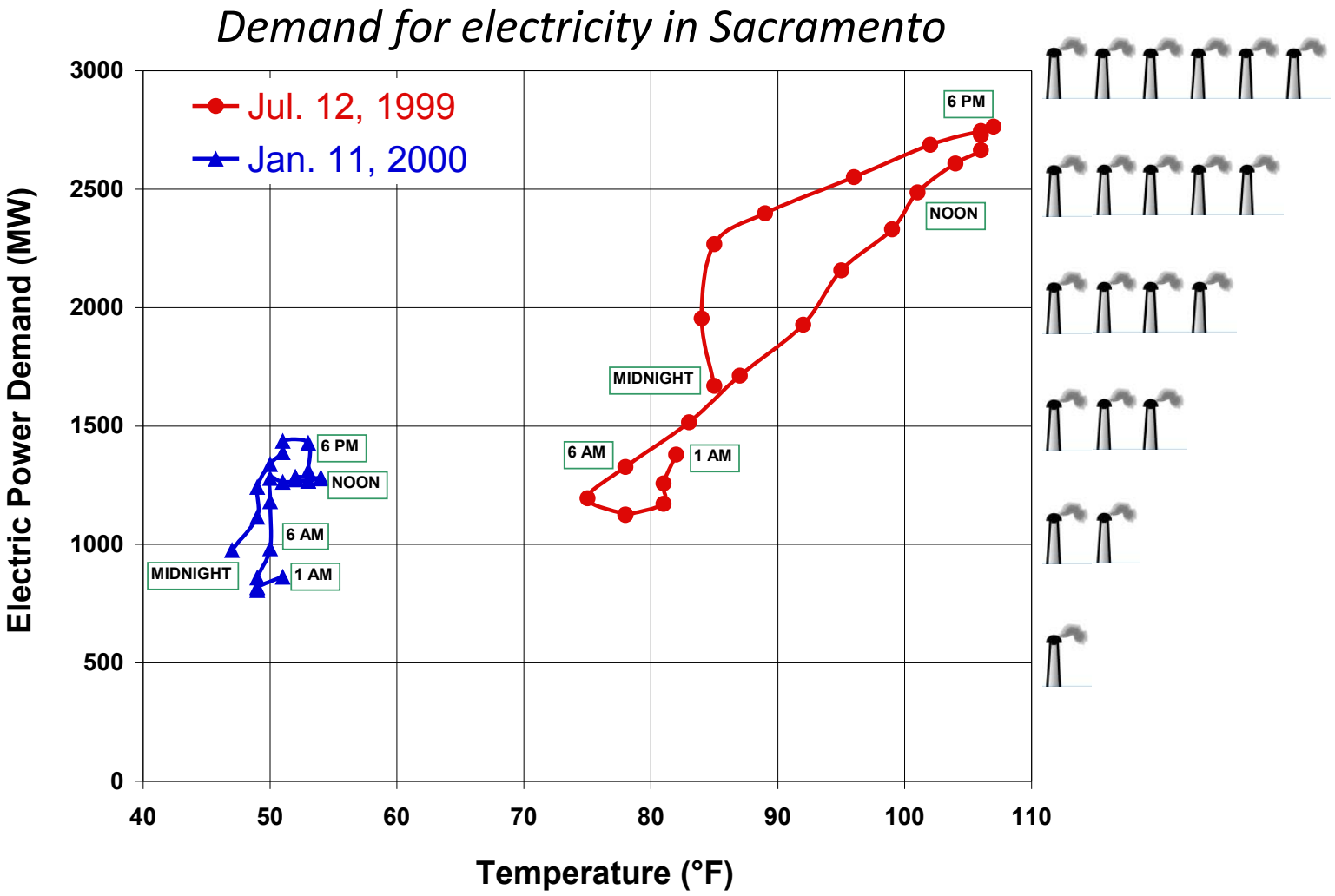
COOL SCIENCE

FriendsofBerkeleyLab.lbl.gov

Summer in the city

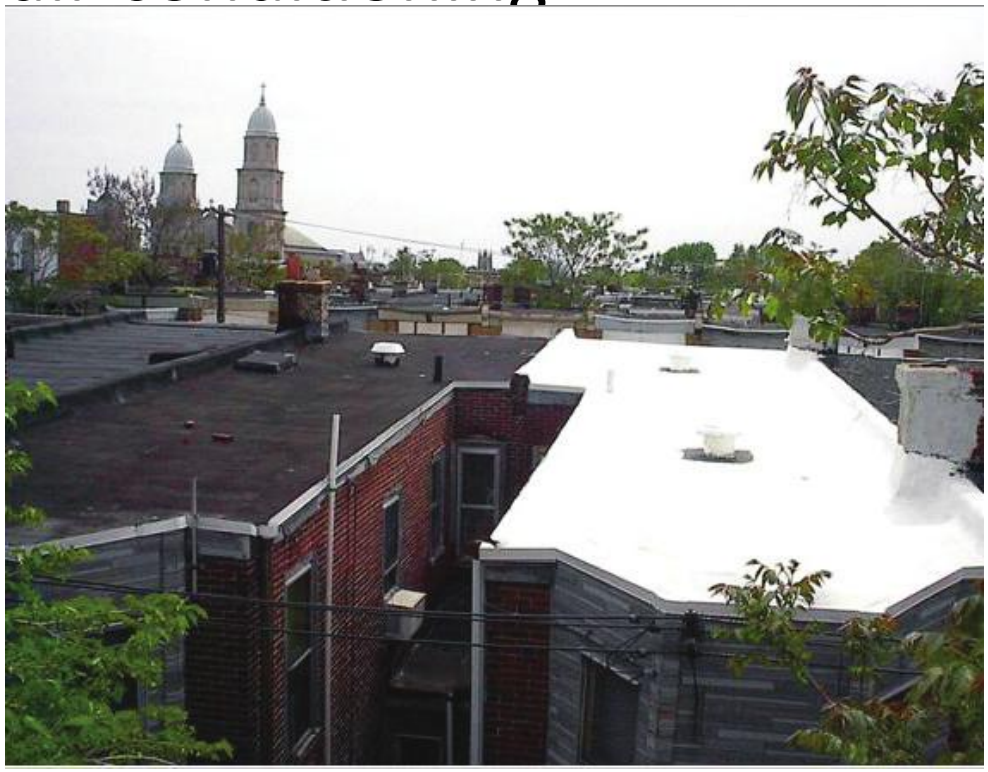


Cool the city, save electricity



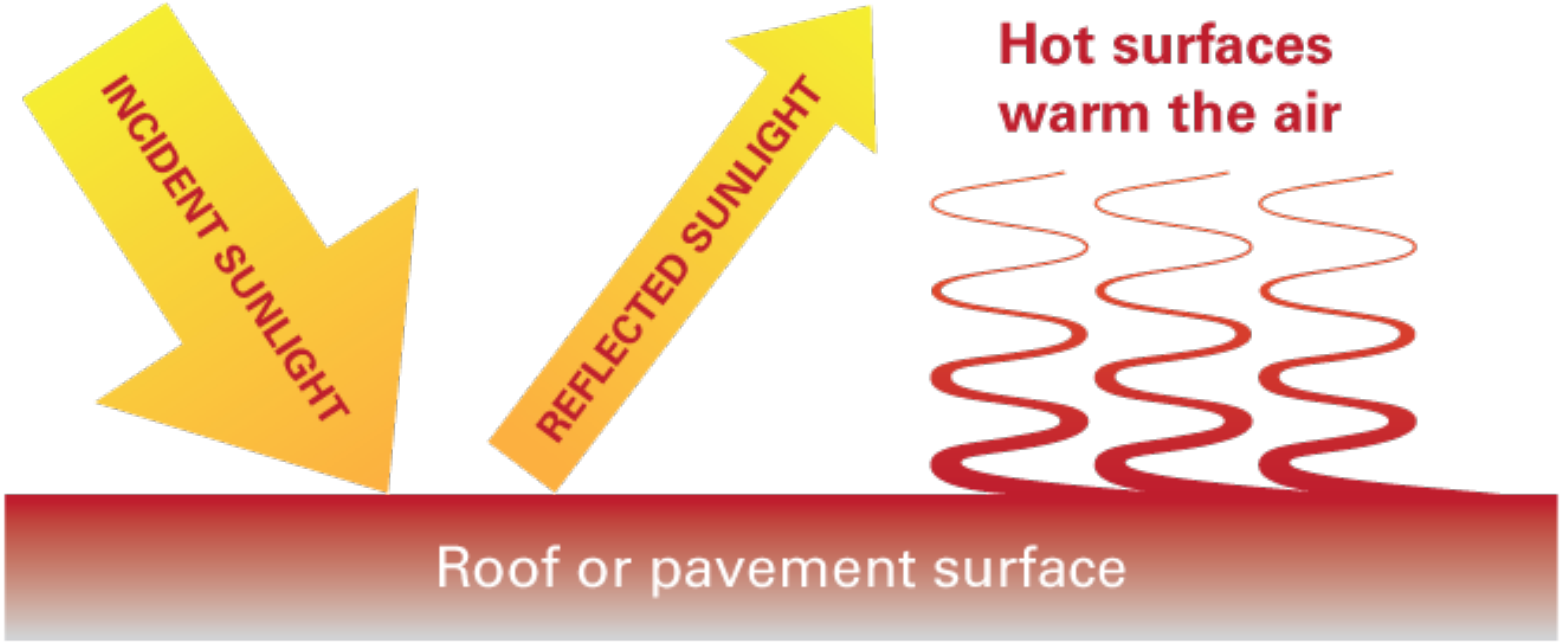
30,000 deaths in European heat wave (2003)
739 deaths in Chicago heat wave (1995)

- In Chicago, virtually all of the deaths occurred on the top floors of black-roofed buildings without air conditioning



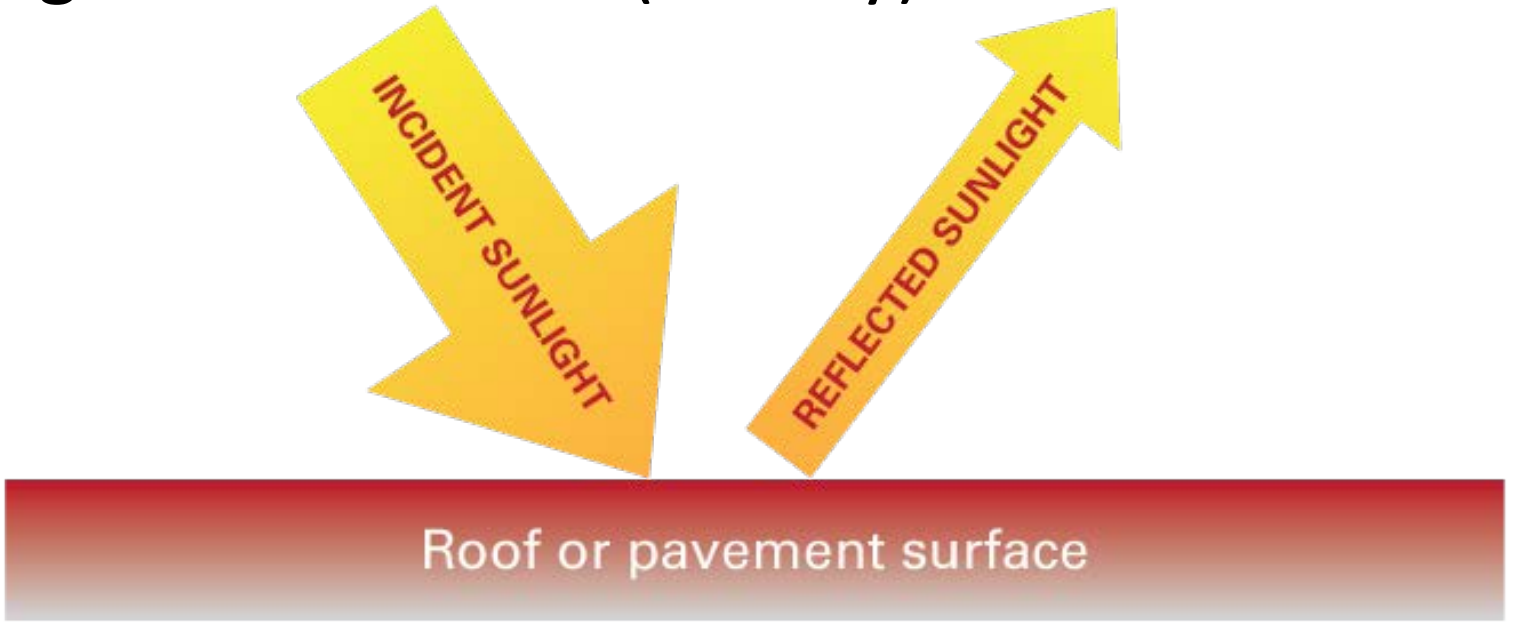
How is air heated?

- Sunlight does not directly heat the air.
- Opaque surfaces (e.g., pavements & roofs) absorb some of the sunlight.

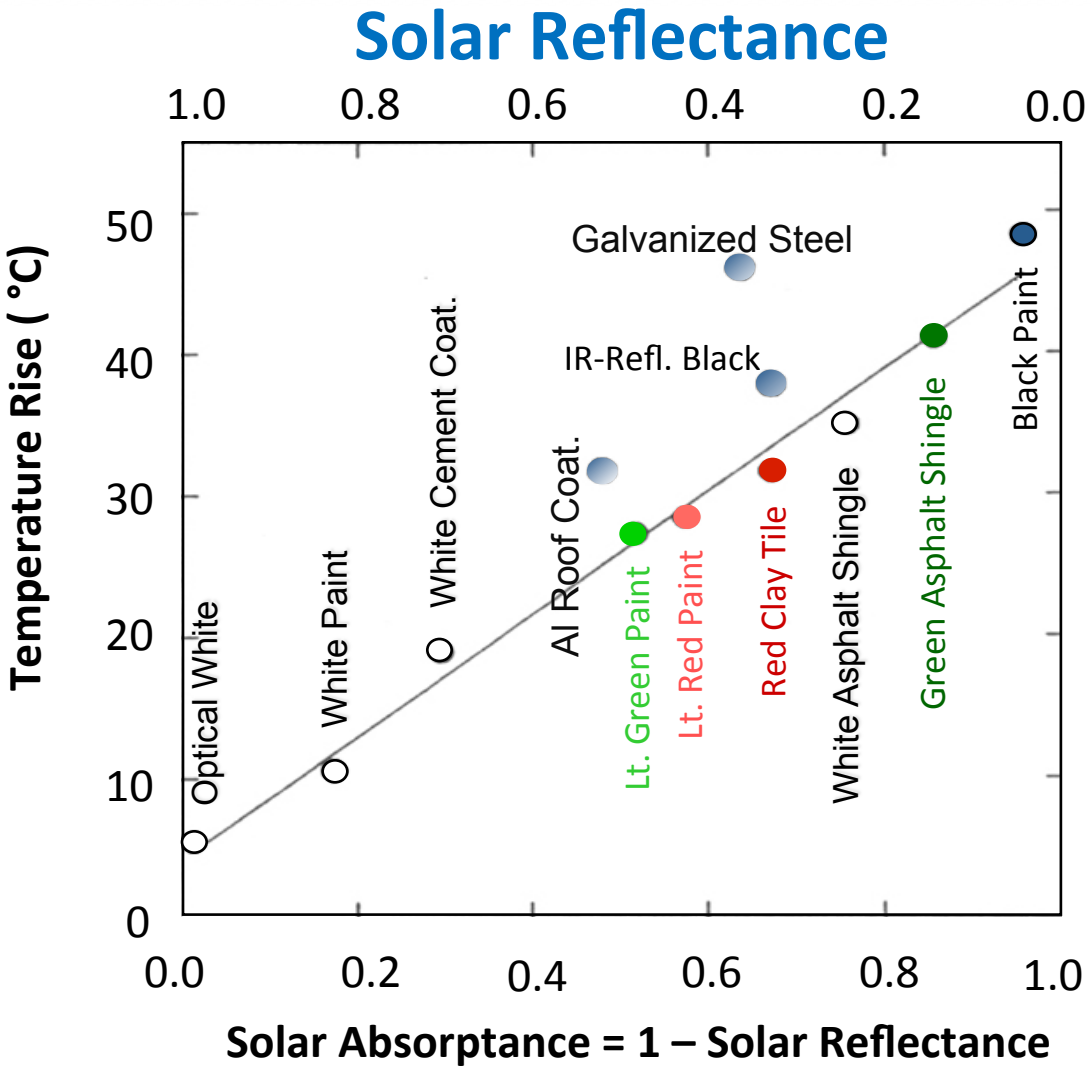


Solar reflectance (SR)

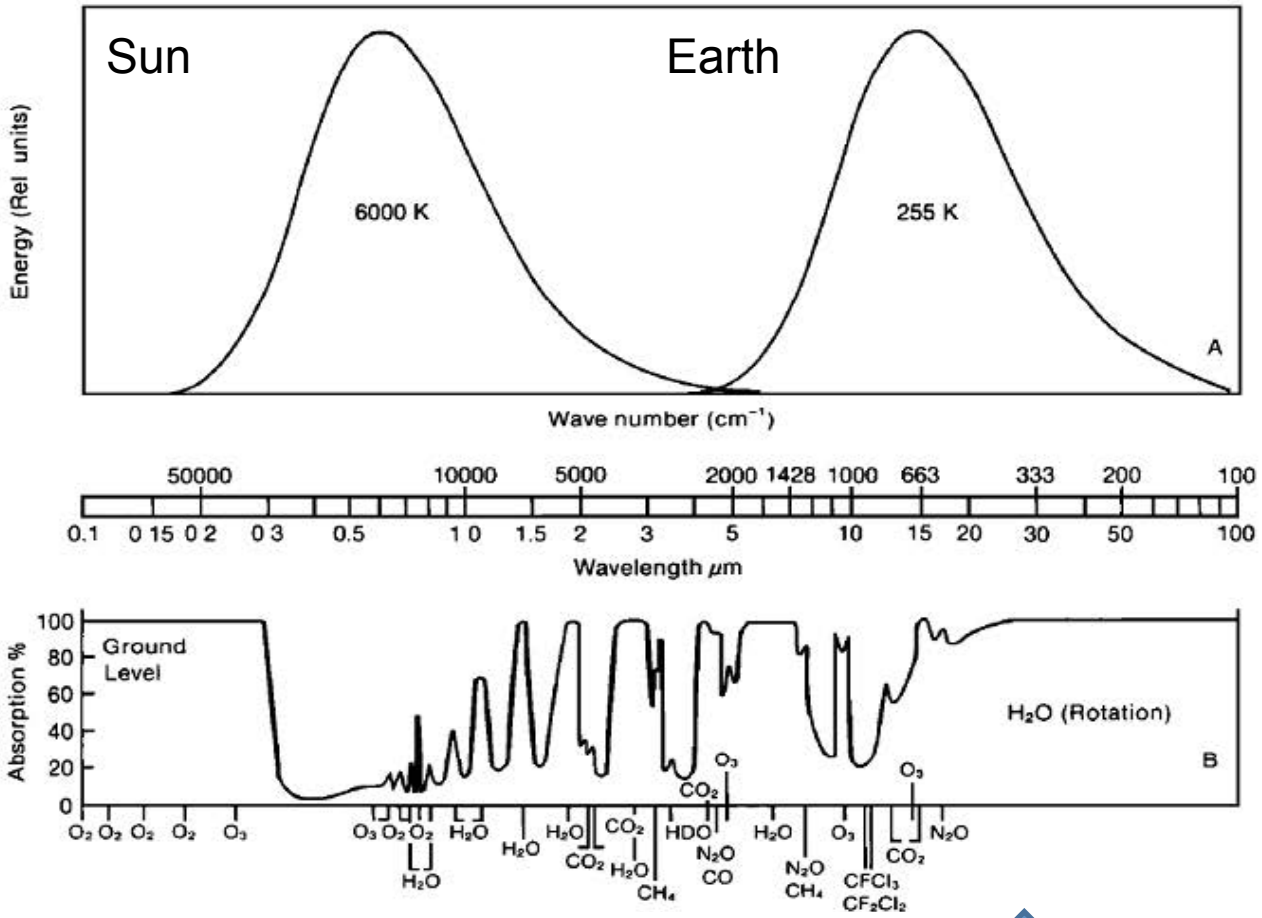
- SR = fraction of sunlight reflected =
  reflected sunlight ÷ incident sunlight
- Scale is 0 - 1 (or 0 - 100%)
- Higher SR is cooler (usually)



Reflective roofs stay cooler in the sun



Atmospheric greenhouse effect (i/ii)



Absorption by the atmosphere.

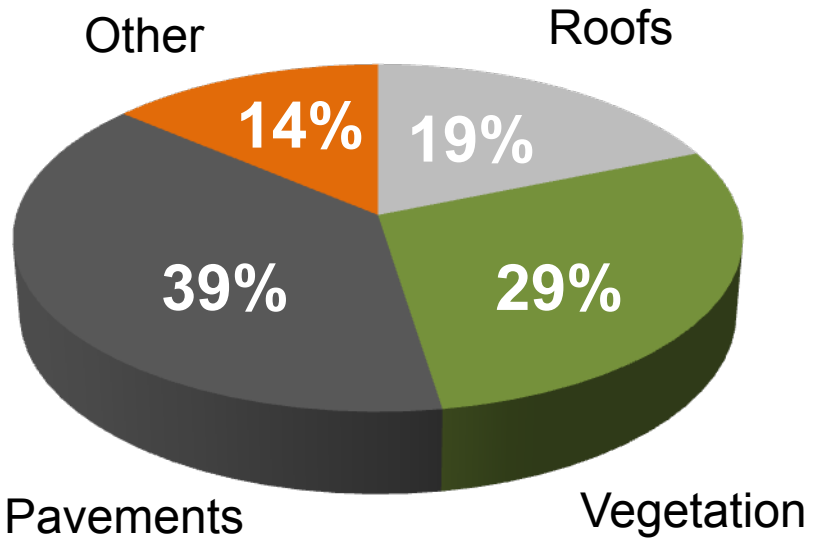
Atmospheric greenhouse effect (ii/ii)

1. Sunlight heats the Earth.
2. Earth re-radiates thermal infra-red radiation (TIR).
3. Nearly all of the TIR is trapped by gases (H_2O, CO_2, O_2, …).
4. This is the "atmospheric greenhouse" effect.
5. **Increasing greenhouse gas concentrations warms the earth.**

What can we make cooler?

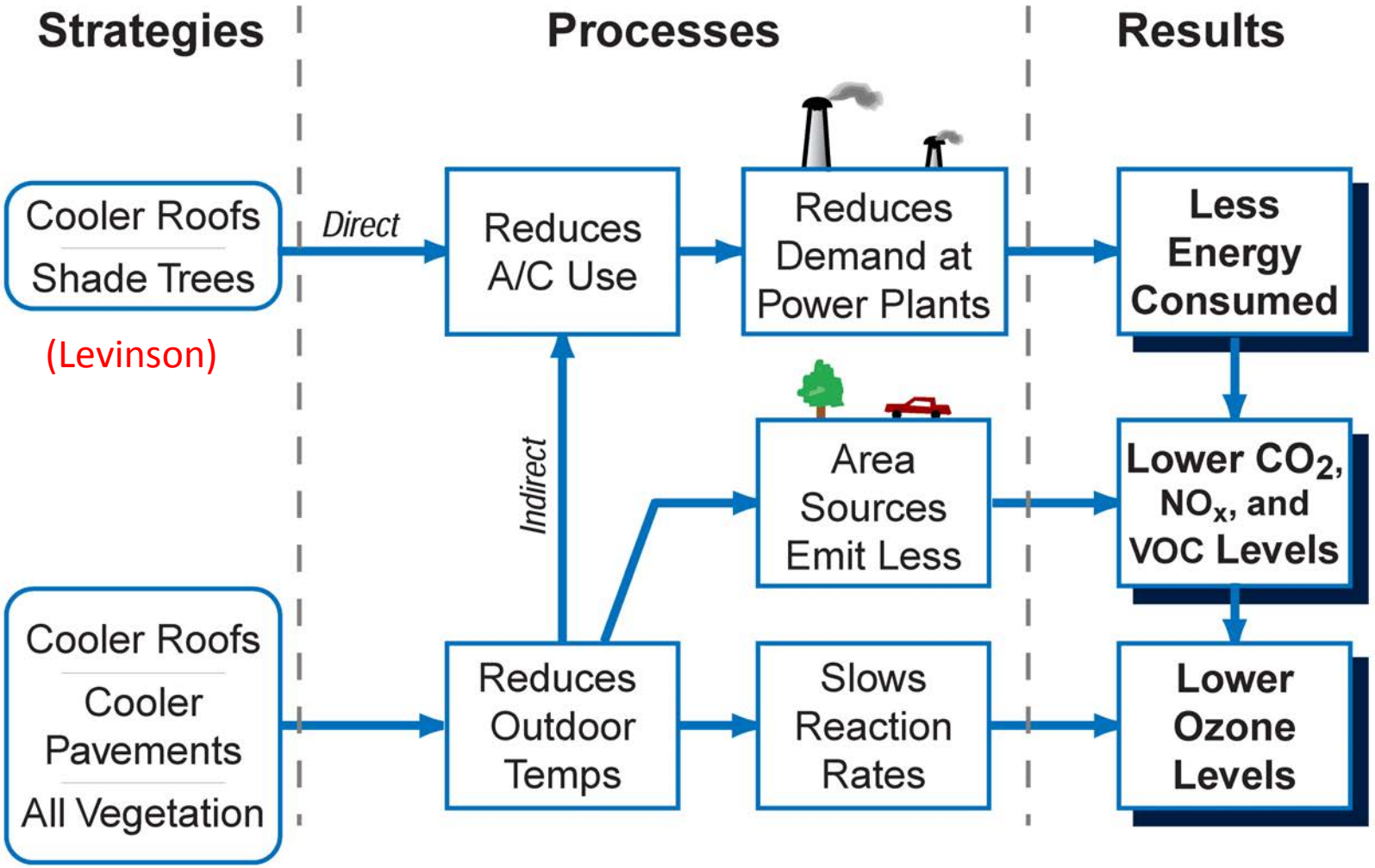
Sacramento ≈ 1 km^2

There are many man-made dark surfaces.



Urban fabric above tree canopy

Strategies for cool communities…



…and a cooler planet!

- If we reflect sunlight, it mostly passes back out of the atmosphere *without heating the air*.
- Lowering the air temperature by reflecting sunlight is thermally equivalent to removing greenhouse gases from the atmosphere.

Reflective surfaces delay global warming.

(Rosenfeld)

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

Ronnen Levinson, Ph.D.

COOL ROOFS

FriendsofBerkeleyLab.lbl.gov

White roofs, cool-colored roofs

OLD

flat, white

pitched, white

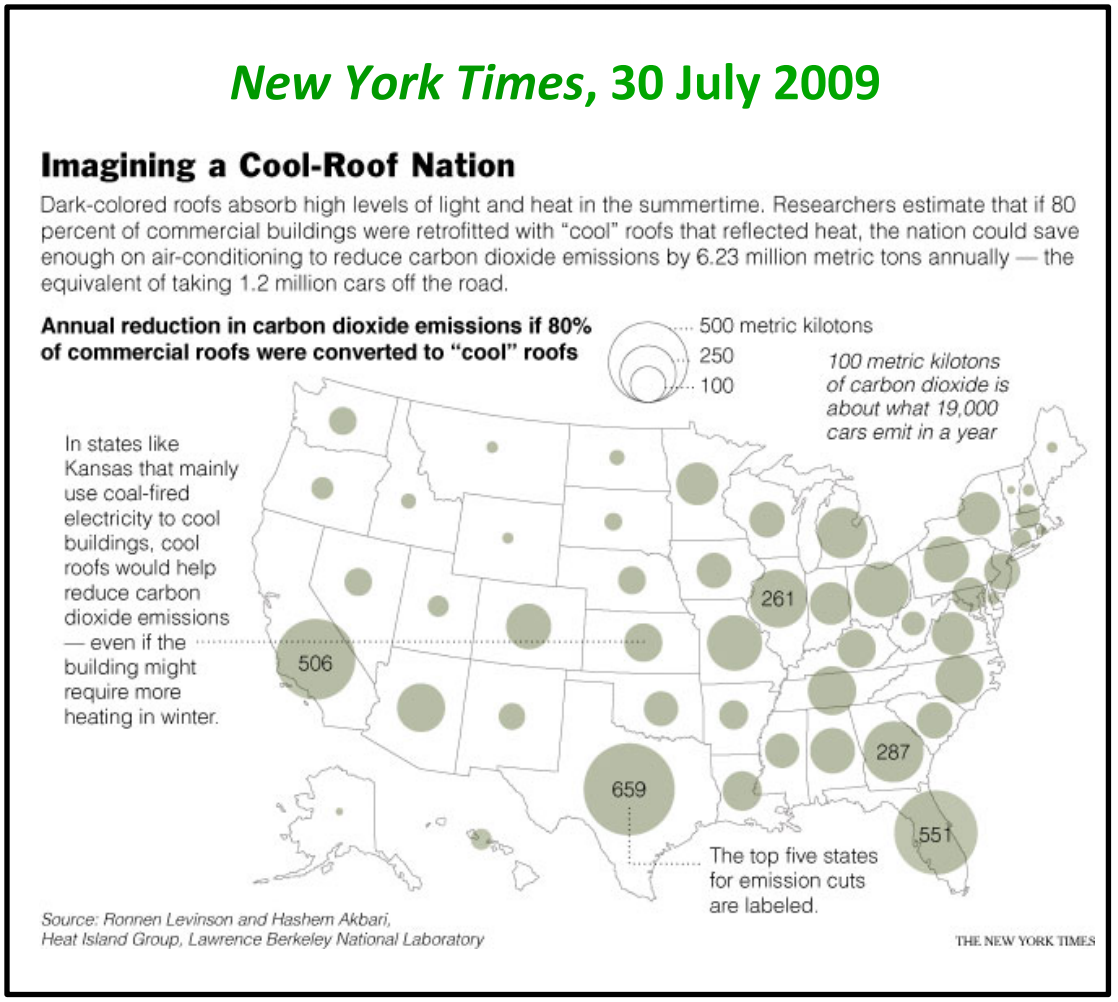
NEW

pitched, cool & colored

Potential U.S. white-roof benefits

- Retrofitting 80% of U.S. air-conditioned commercial buildings (2.1B m^2) would annually save
  - **$735M**
  - **6.2 Mt CO_2 (=1.2M cars)**
  - **9.9 kt NO_x (=0.6M cars)**
  - 26 kt SO_2
  - 126 kg Hg

  through energy conservation
- Product lifetime energy savings has present value of $11B

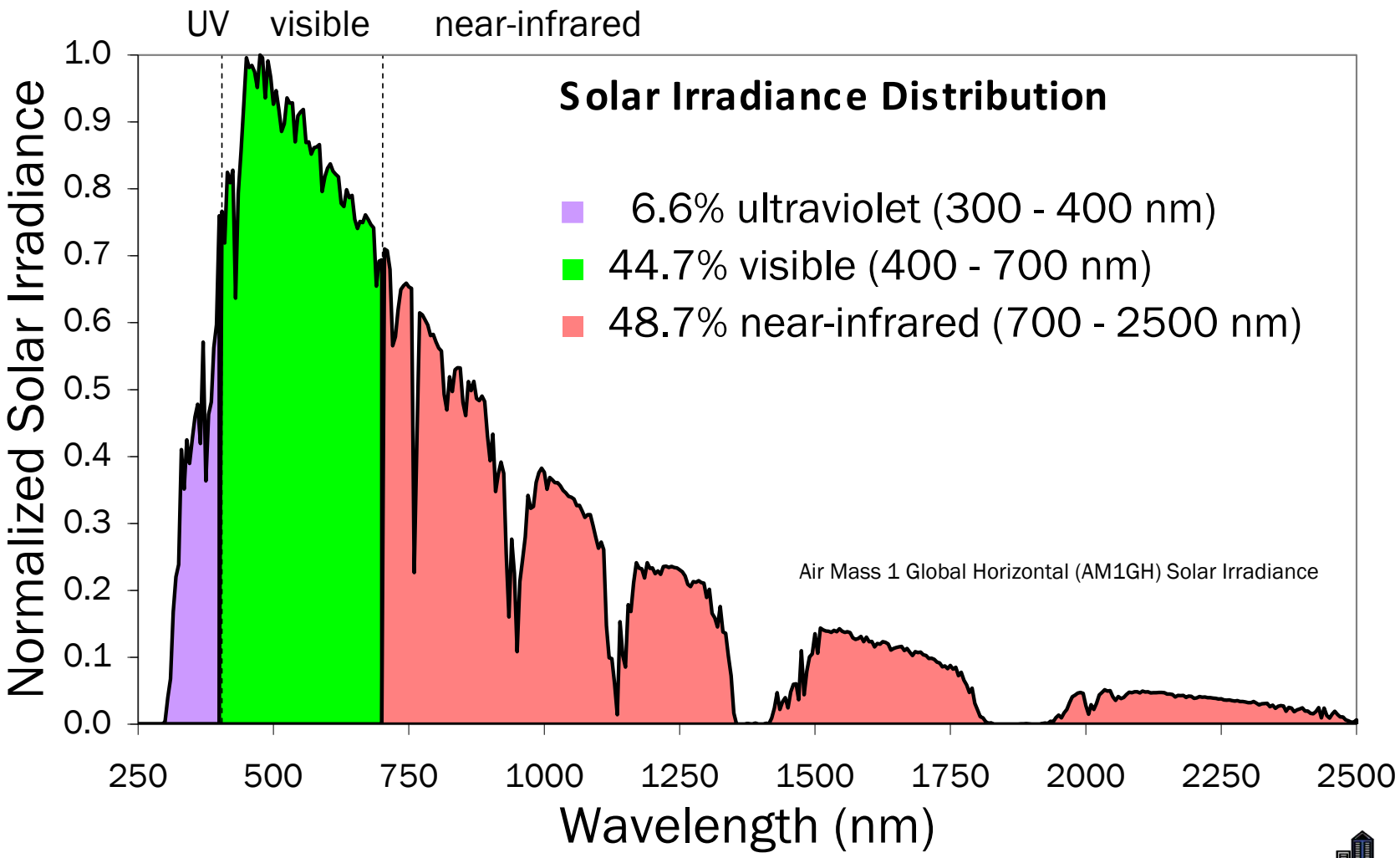


LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

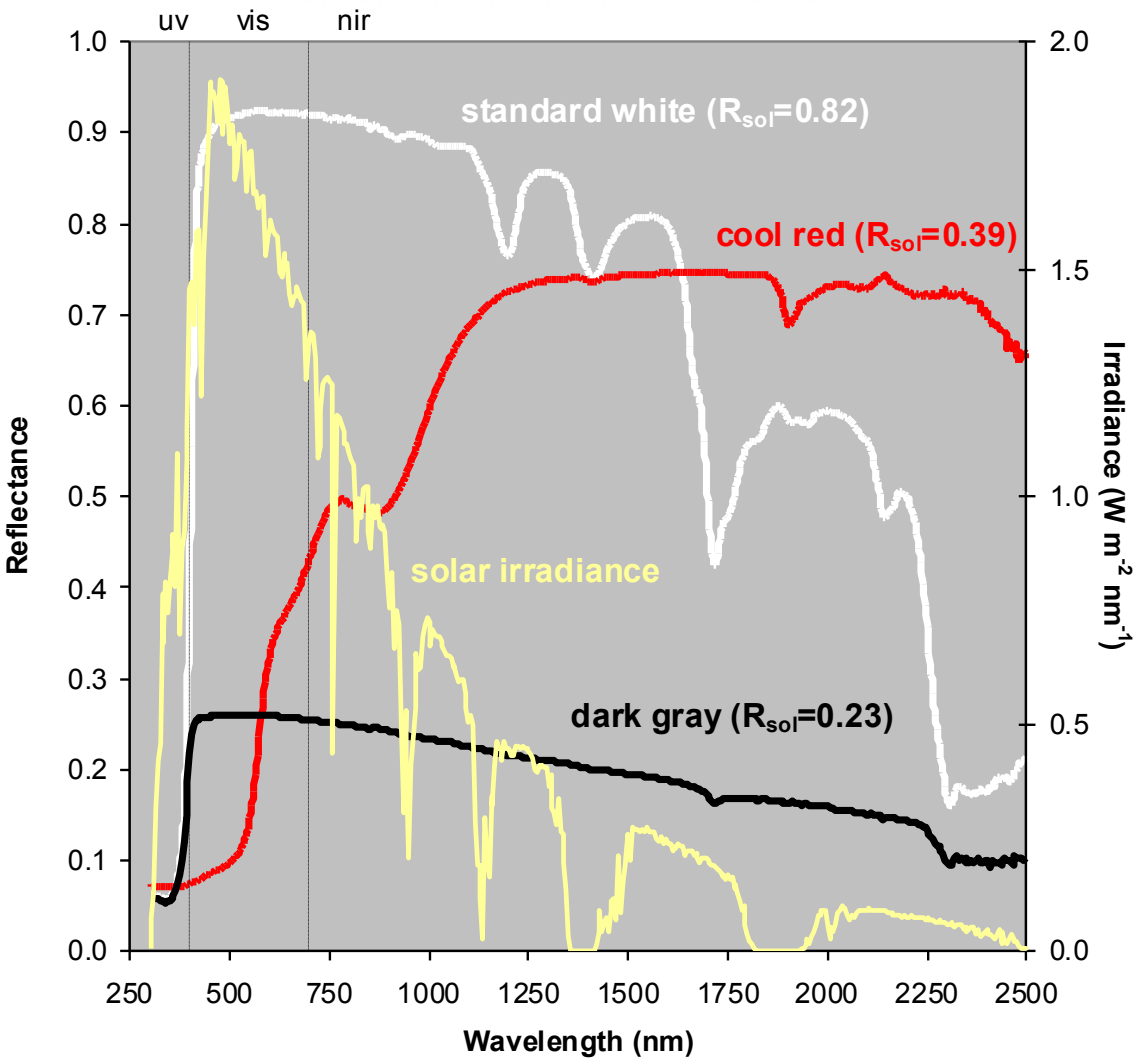
COOL CITIES, COOL PLANET

Cool Colors

Sunlight — more than meets the eye



White, cool color, warm color



white roof

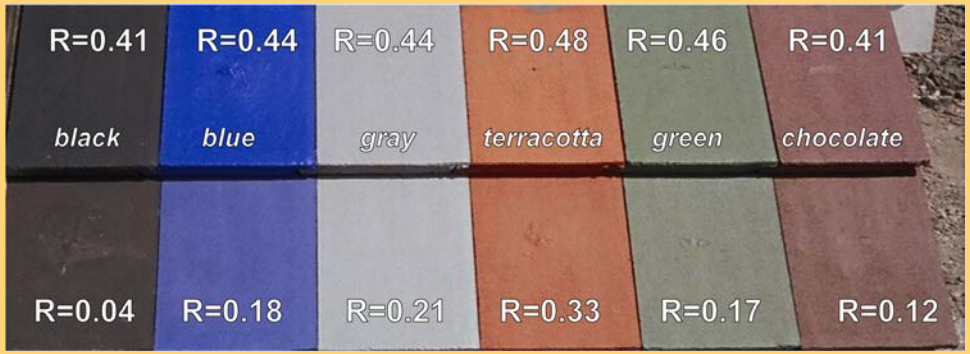
cool red roof

gray roof

Cool colored roofs available today

cool concrete tile
R ≥0.40

standard concrete tile
(same color)

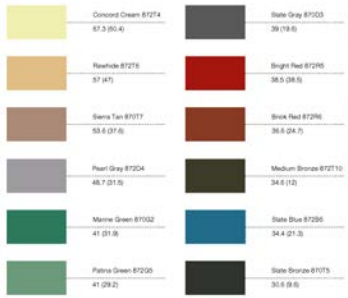


Courtesy
American
Rooftile
Coatings

solar reflectance gain =	+0.37	+0.26	+0.23	+0.15	+0.29	+0.29

cool clay tile
R ≥0.40

Courtesy
MCA Clay Tile



cool metal
R ≥0.30

Courtesy
BASF Industrial
Coatings

cool fiberglass asphalt shingle
R ≥0.25
Courtesy
Elk Corporation

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

Cool roofs of tomorrow

Advanced cool-colored asphalt shingles

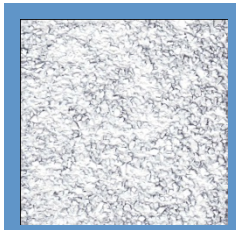
today's cool asphalt shingles reflect ≈ 25% of sunlight

Courtesy
Elk Corporation

Solar reflectance ≥ 25%

Prototype cool-colored asphalt shingles

- **reflect up to 35% of sunlight**
- **can save up to 60% more energy**



Bright-white shingle
SR > 60%

Advanced white roof coatings, membranes

Both roofs exposed for 9 years in Florida

Kynar® based coated metal roof with 0.80 Total Solar Reflectance

Elastomeric Acrylic over PVC with 0.55 Total Solar Reflectance

White metal roof stays clean, saving 70% more energy than soiled white coating.

- **White roof coatings, membranes soil rapidly, lose solar reflectance (SR)**
  - initial SR ≈ 0.80
  - aged SR ≈ 0.55
- **How to keep white roofs clean and reflective?**
  - reduce leaching of plasticizers
  - decrease surface roughness & stickiness
  - photocatalytic self-cleaning
  - photoinduced hydrophilicity

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

Melvin Pomerantz, Ph.D.

COOL PAVEMENTS

FriendsofBerkeleyLab.lbl.gov

Types of pavement

asphalt concrete

=

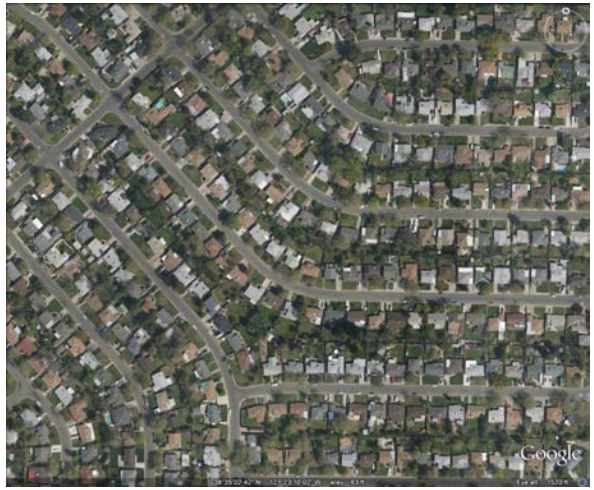
“asphalt”

cement concrete

=

“concrete”

Pavements cover about one-third of cities



Of that third, about

- 50% are streets (usually asphalt concrete)
- 40% are exposed parking (usually asphalt concrete)
- 10% are sidewalks (usually cement concrete)

Asphalt concrete – solar reflectance

Fresh asphalt concrete has an SR about 5%.

As it ages, its SR increases to about 15%.

Cooler asphalt pavements

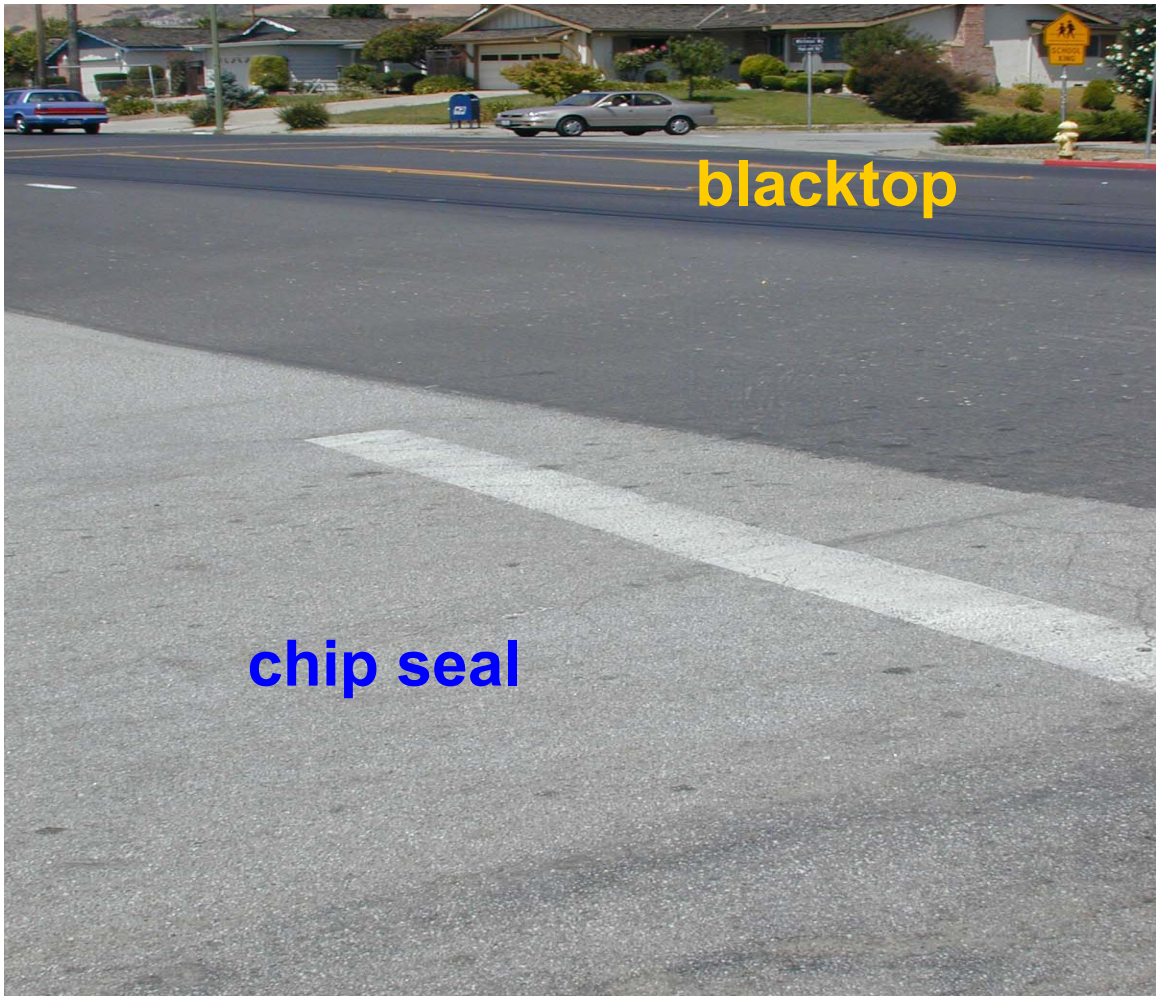
- ***New* pavement:** Use light-colored aggregate
  - Aggregate shows as the binder rubs off
    - Light-colored rock
    - Sea shells
    - Porcelain, etc.
- ***Older* pavement:** Use light-colored aggregate in surface coatings ("chip seals")

- **Depends on availability of <u>suitable</u> aggregate**
  - Don't want to ship heavy rocks over long distances

Light-colored chip seal in San Jose, CA

The side streets are resurfaced with light-colored chip seals.

The main road is "black-topped".



Cement concrete – solar reflectance
(traditional gray-cement concrete)

Fresh cement concrete has an SR about 35%.

NEW AGED

As it ages, its SR decreases to about 20%.

Cooler cement concretes

- **Cool**. Gray-cement concrete with light colored fine aggregate: initial SR ≈ 40%
- **Cooler**. Slag concrete, in which slag replaces about 50% of gray cement: initial SR ≈ 60%
- **Coolest**. White-cement concrete: initial SR ≈ 70%

Traditional gray-cement concrete

White-cement concrete

Courtesy Concrete Technology Laboratory

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

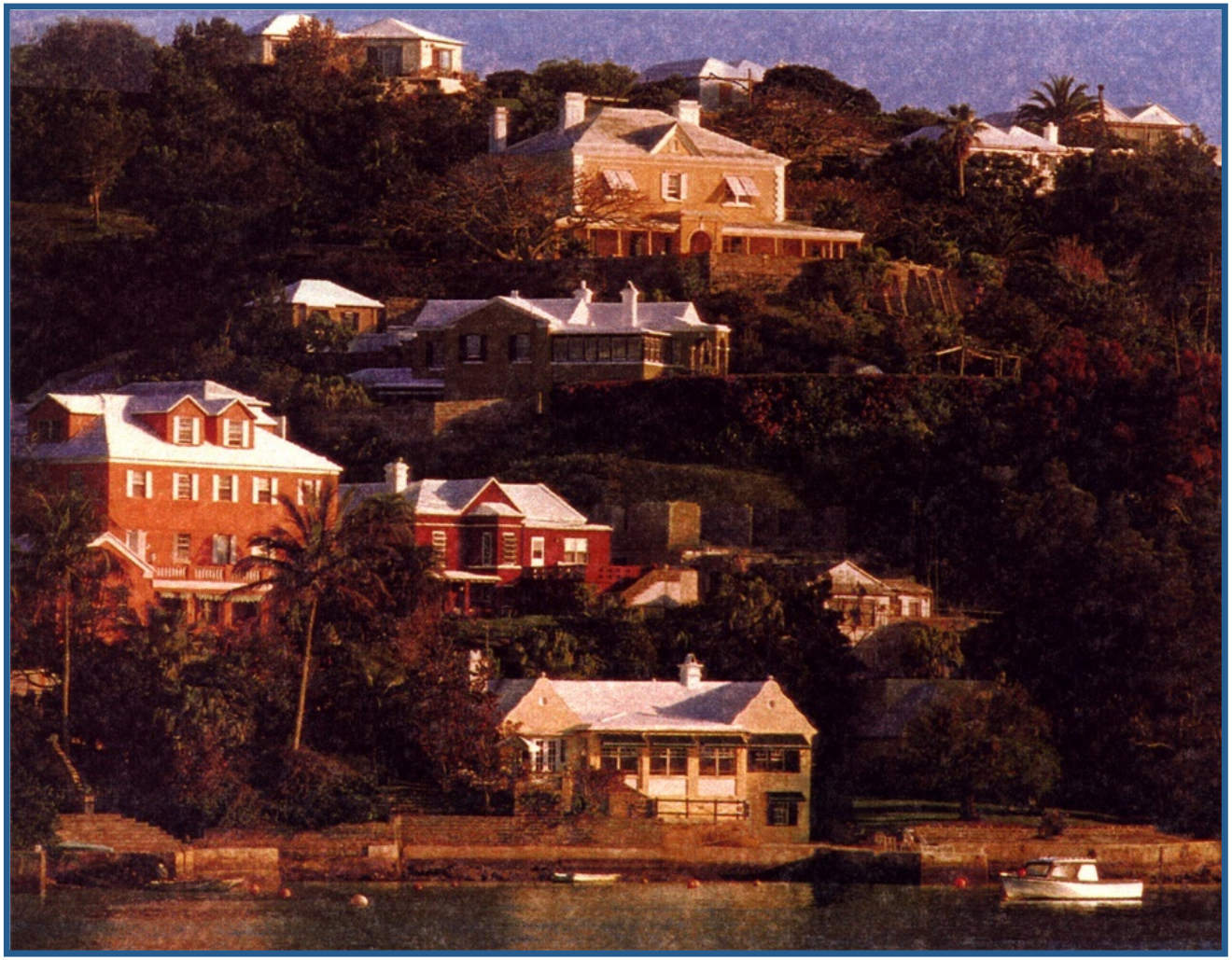
COOL CITIES, COOL PLANET

Arthur H. Rosenfeld, Ph.D.

WHITE ROOFS AROUND THE WORLD

FriendsofBerkeleyLab.lbl.gov

White is “cool” in Bermuda



…in Santorini, Greece

…in Hyderabad, India

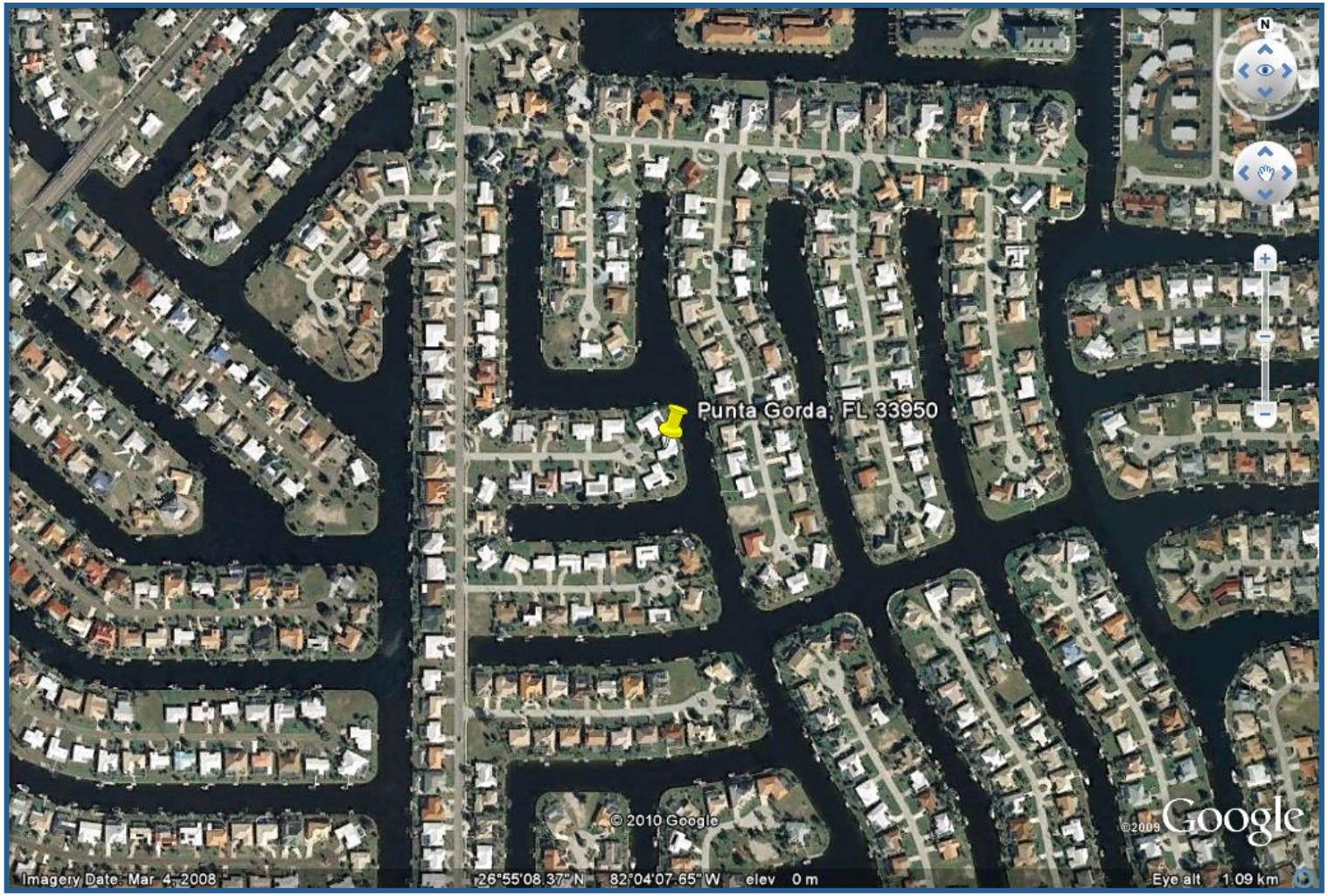
…and widely in the state of Gujarat, India.

Walmart store in Northern California

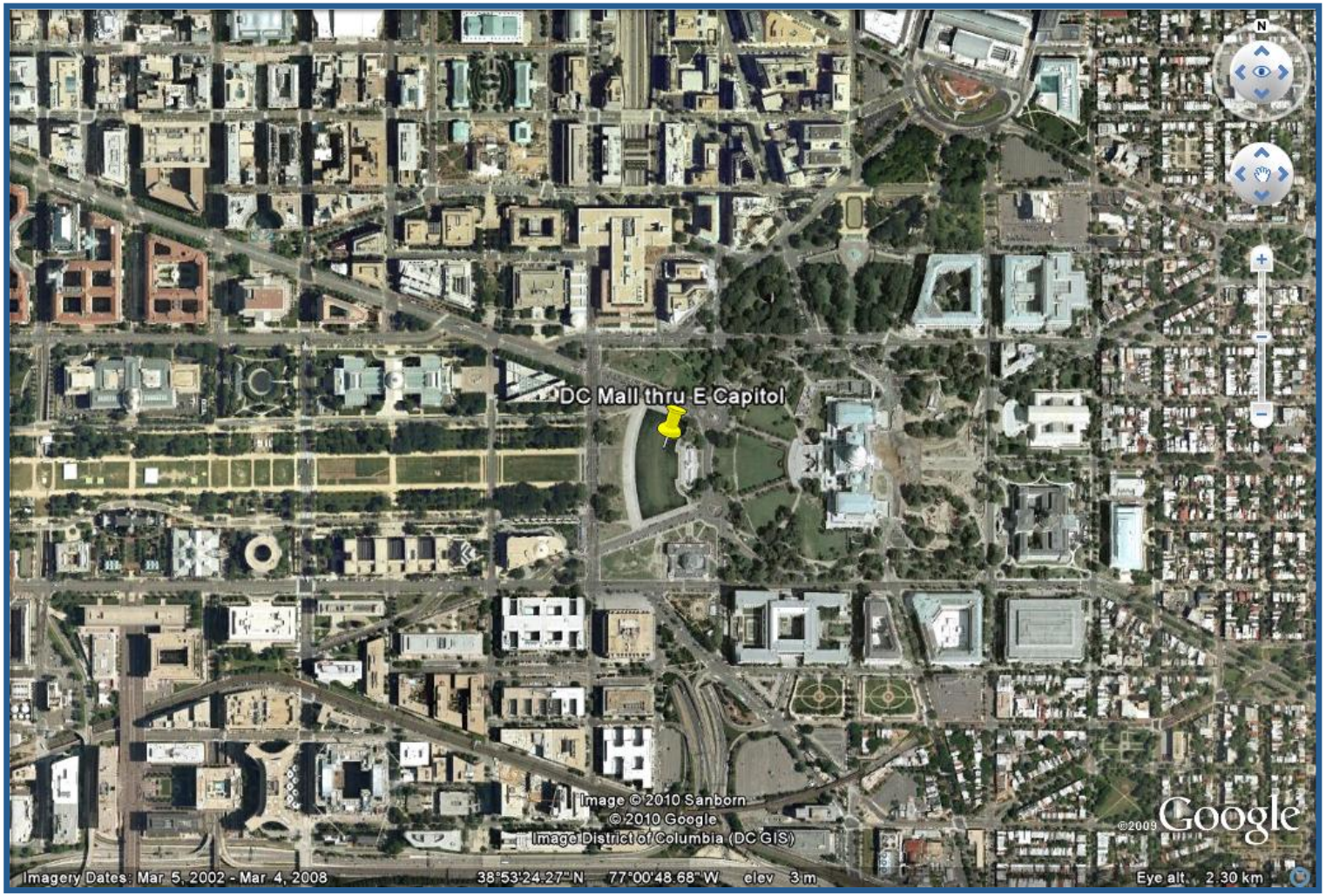
Congratulations to UC Davis

White roofs are popular in Tucson, AZ

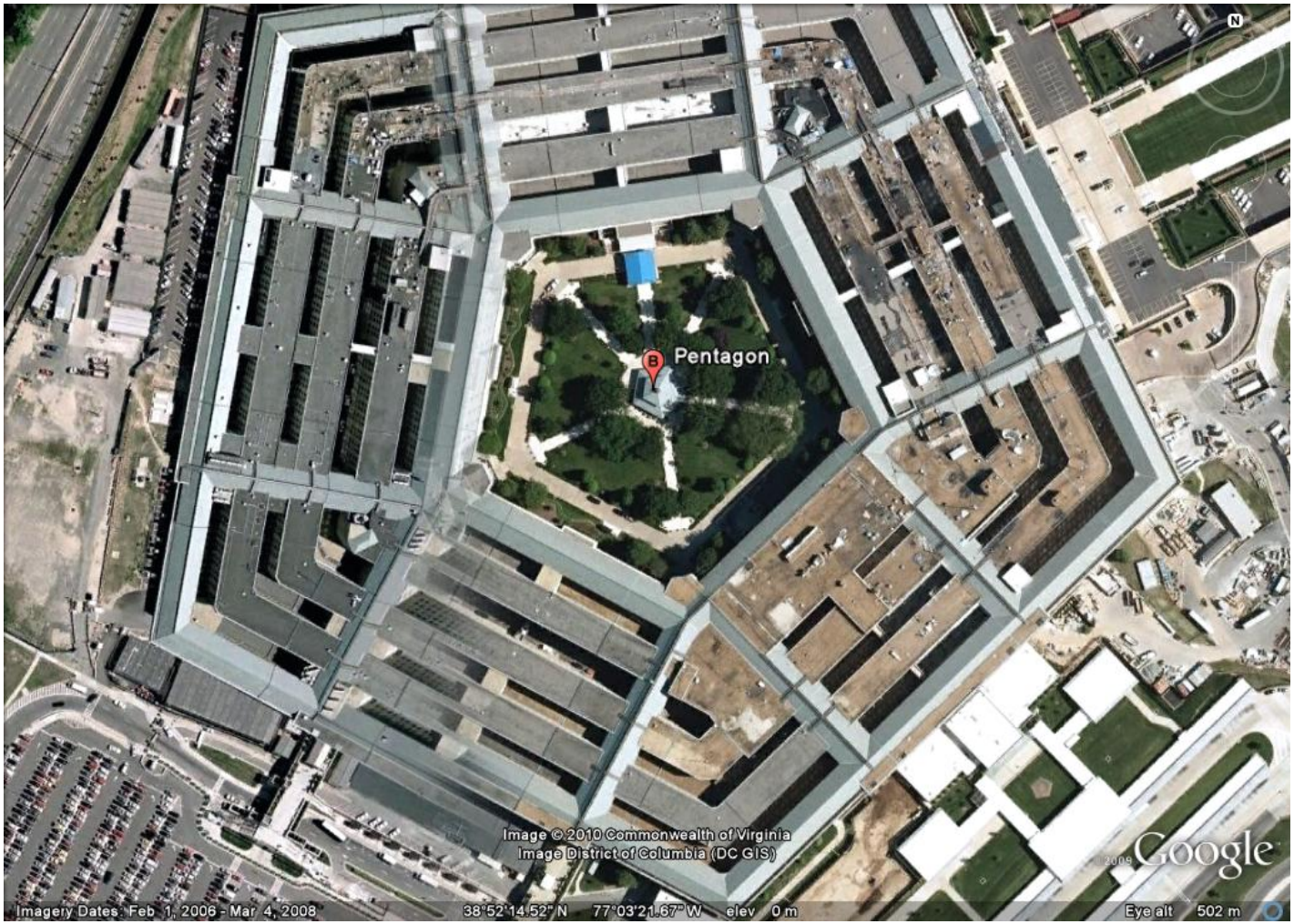
…and in Punta Gorda, FL



Washington, DC (Federal) has problems



Pentagon


Pentagon
Image © 2010 Commonwealth of Virginia
Image District of Columbia (DC GIS)
Google
Imagery Dates: Feb 1, 2006 - Mar 4, 2008
38°52'14.52" N 77°03'21.67" W elev 0 m
Eye alt 502 m

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

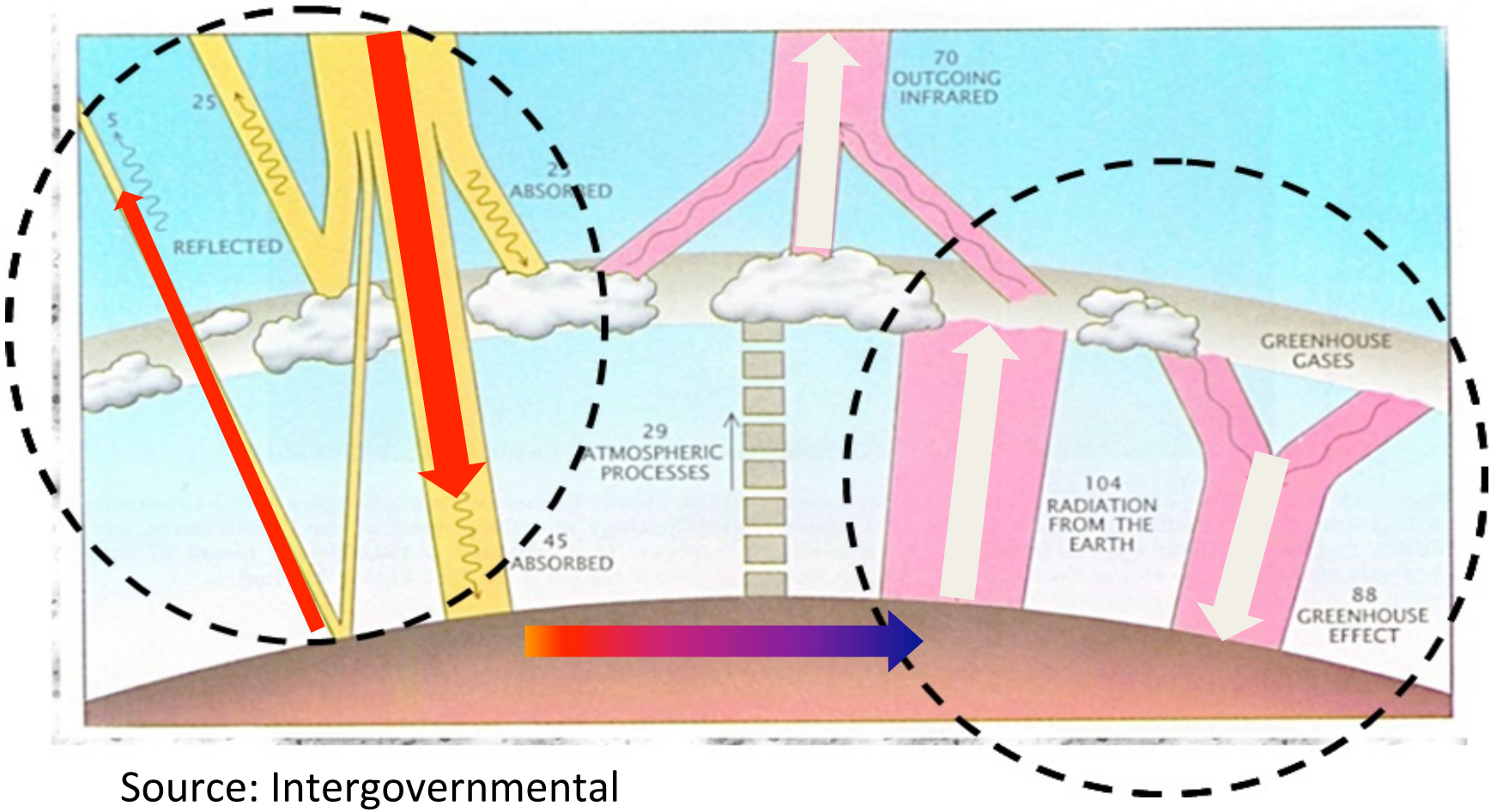
COOL CITIES, COOL PLANET

Arthur H. Rosenfeld, Ph.D.

COOLING OUR PLANET

FriendsofBerkeleyLab.lbl.gov

Solar-reflective surfaces cool the globe via "negative radiative forcing"



Source: Intergovernmental Panel on Climate Change (IPCC)

GLOBAL COOLING: Making 100 m^2 (1000 ft^2) of gray roofing white offsets **emission** of 10 t of CO_2

How much CO_2 equivalent is offset if we whiten all eligible urban flat roofs world-wide? (i/ii)

- Answer: **24 Gigatonnes (Gt)**
  - 2/3 of a year's worldwide emission
  - Gigatonne = billion metric tons

- If implemented over 20 years (the life of a roof or a program) this is ≈ 1.2 Gt/year.

How much CO_2 equivalent is offset if we whiten all eligible urban flat roofs world-wide? (ii/ii)

- Offset is equivalent to **taking 300 million cars off the road for 20 years**.
  - There are about 600 million passenger cars world wide, and they each emit ≈ 4 t CO_2/ year.

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

What to do now

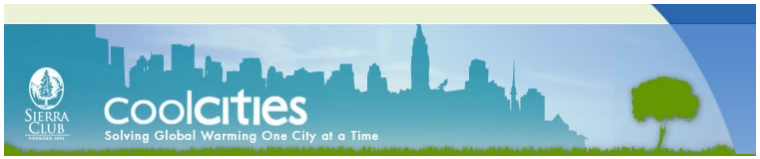
Progress in energy efficiency standards

- In 2005, California's "Title 24" energy efficiency standards prescribed white surfaces for low-sloped roofs on commercial buildings.
- In 2008, California prescribed "cool colored" surfaces for steep residential roofs in its 5 hottest climate zones.
- Arizona, Florida and Georgia followed.
- **Other U.S. states & all countries with hot summers should follow.**

Recent cool roof progress (2005 – 2011)

- 2005
  - California Title 24 – "Flat roofs shall be white" (15 climate zones)
  - EPA ENERGY STAR lists Cool Roof Materials
- 2010
  - June 1st, 2010 – Memo from U.S. Energy Secretary Steven Chu calls for all DOE Buildings to have white roofs, if cost-effective
  - June 16th, 2010 – Marine Corp follows suit, Pentagon scratches head
  - June 19th, 2010 – *RetroFIT Philly* announces winner of "coolest block" contest to white-coat black roofs of row houses.
- 2011
  - 100 Cool Cities launched – see www.WhiteRoofsAlliance.org
  - Spring 2011 – US will offer, at G20 Energy Ministers meeting, technical assistance to developing countries who join a cool roof initiative.

100 Cool Cities would unite many initiatives and trade associations



EMERALD CITIES COLLABORATIVE
GREEN • FAIR • DEMOCRATIC

American Council for an Energy-Efficient Economy

THE CLIMATE GROUP

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

Arthur H. Rosenfeld, Ph.D.
Ronnen Levinson, Ph.D.
Melvin Pomerantz, Ph.D.

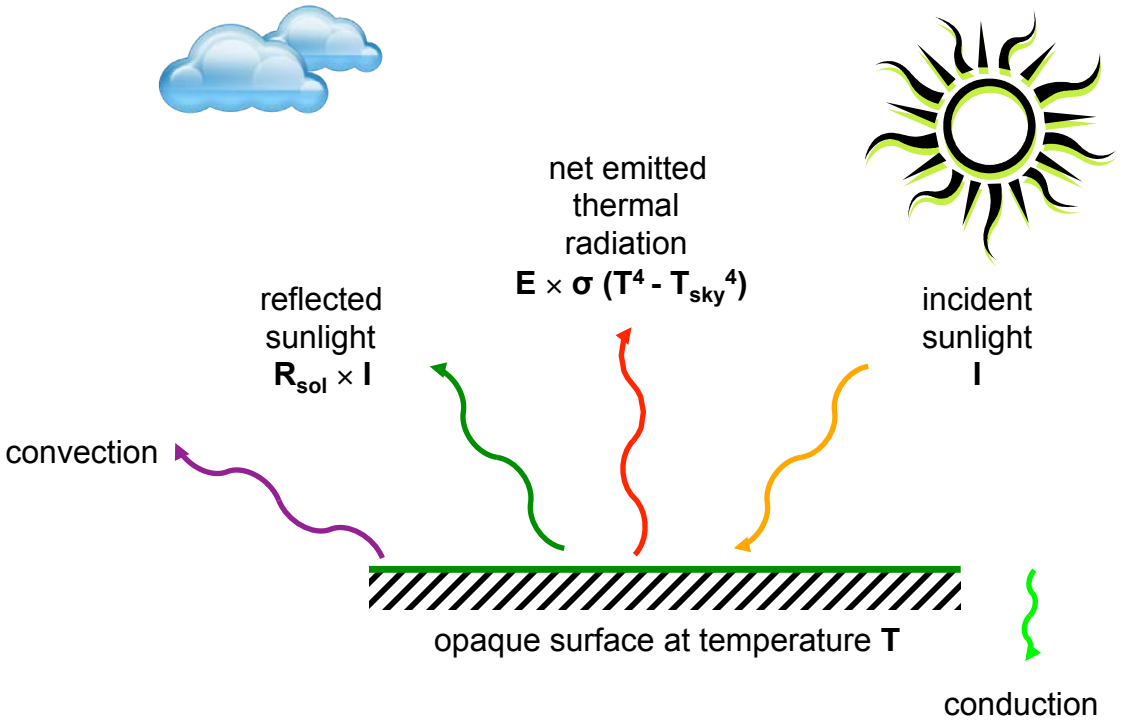
FriendsofBerkeleyLab.lbl.gov

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

Supplemental slides

What makes a surface cool?



- High solar reflectance (R_{sol}) lowers solar heat gain (0.3 - 2.5 µm)
- High thermal emittance (E) enhances thermal radiative cooling (4 - 80 µm)

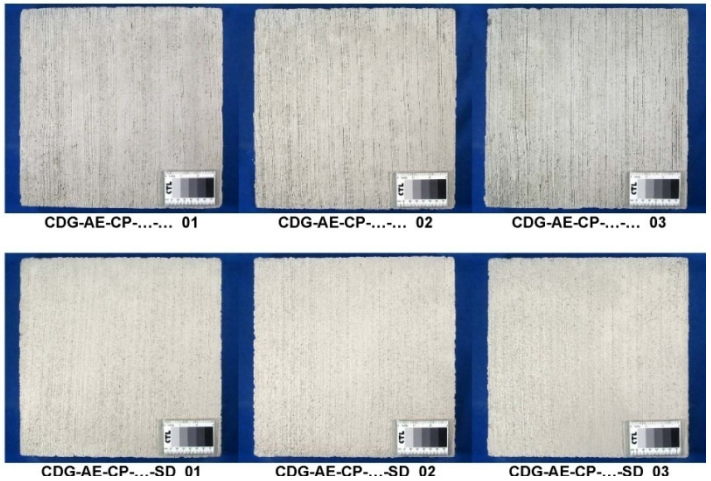
high solar reflectance + high thermal emittance = **low surface temperature**

Surface temperature in Atlanta, GA

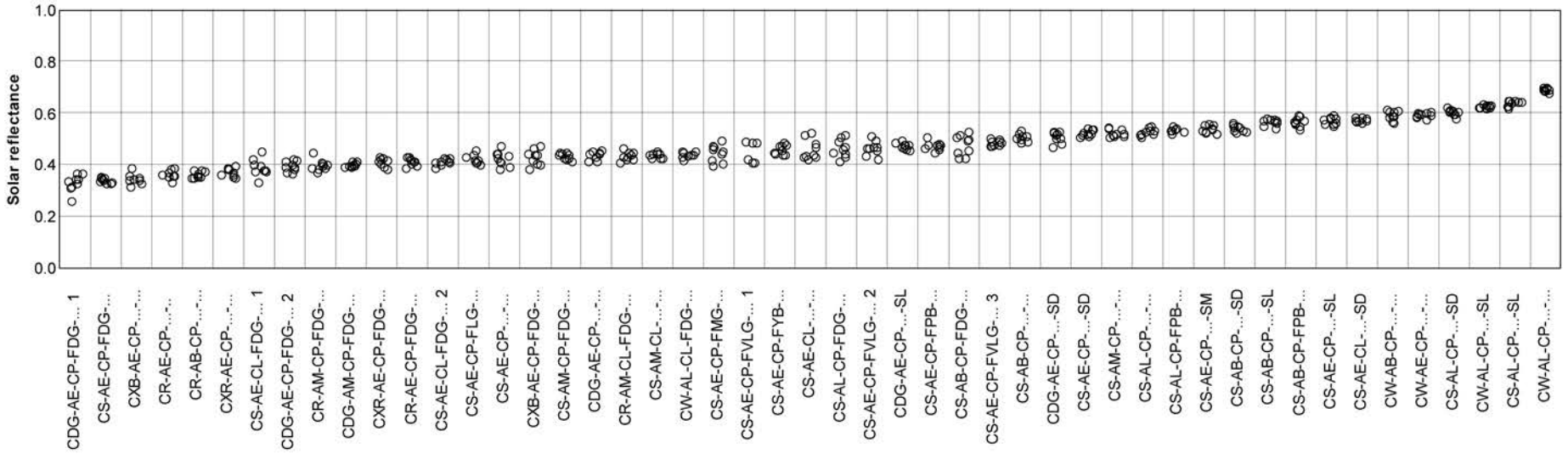
Heat Island Group, Lawrence Berkeley National Laboratory

Cool pavement technology: cement concrete

- Study by Portland Cement Association shows that cement concretes have solar reflectances of 0.30 – 0.65
- LEED compliant (SRI ≥ 29)



Solar reflectances of 45 concrete mixes



Resin binders

- SR: varies depending on aggregate
- Uses:
  - new construction, preventive maintenance
  - streets, sidewalks, parking lots, plazas, playgrounds

Resin binders

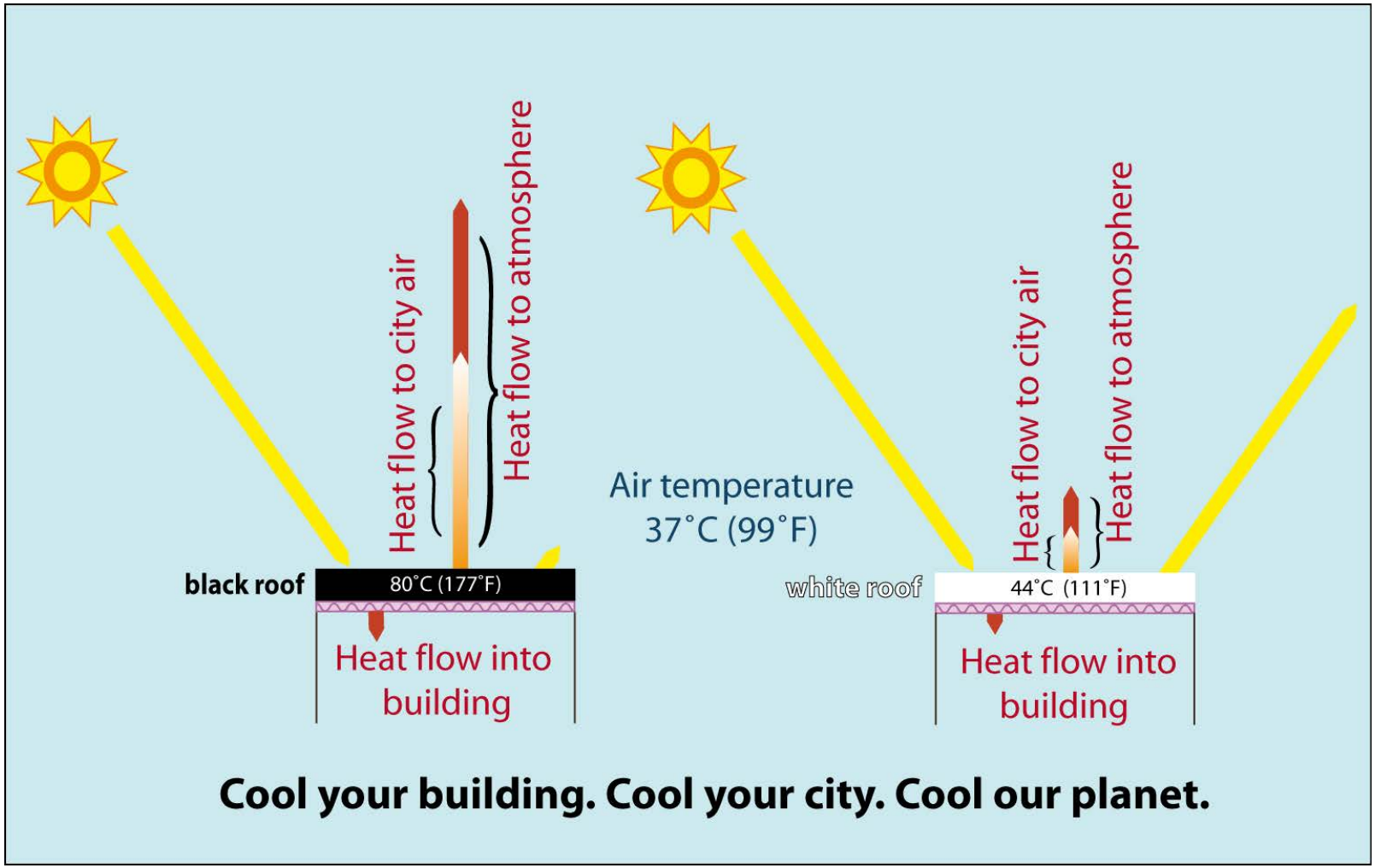
Clear resin binder

Pervious / porous / permeable pavements

- Derives cooling from entrapped water
- Uses:
  - Rain water control, streets, shoulders, sidewalks, paths, alleys, parking lots, plazas, playgrounds
  - Can be made with any binder. (Use one size of aggregate so there are channels through the pavement.)

Water flows very freely through a pervious pavement

White roofs cool your buildings and cities and (this is NEW)… our planet!



3 papers and 1 memo estimate tonnes of CO_2 offset by 100 m^2 (1000 ft^2) of white roofing

	Study (Available at CoolWhitePlanet.org)	Method	Cloud cover esti-mation	CO_2 offset (atmos-pheric) per 100 m^2	CO_2 offset (emitted) per 100 m^2	World-wide potential CO_2 offset (emitted) from cool roofs	CO_2 offset compared to Akbari et al. 2009
1	Akbari et al. 2009 (LBNL)	Calculation	≈ 50%	5.5 t	10 t	24 Gt	100%
2	Menon et al. 2010 (LBNL)	GCM + land use model (summer only)	GCM	7 t	13 t	30 Gt	130%
3	Oleson et al. 2010 (NCAR) [CO_2 values from private communication between Oleson & Menon]	GCM + urban canyon model	GCM	7 t	13 t	30 Gt	130%
4	VanCuren et al. 2010 (CARB)	Measured solar radiation	not needed	3 t	5 t	Addresses CA only; coastal CA is foggy	50%

It is assumed that of 1 tonne of CO_2 *emitted* only 0.55 tonnes remain in the *atmosphere* after one year, so the *atmospheric* and *emitted* columns are just in the ratio of 0.55/1.

Building standards

For planning purposes, follow the lead of the California Public Utilities Commission and **internalize externalities.** Started at \$10/tonne CO_2, and will increase to \$30/tonne CO_2.

Thus, California already plans to incorporate externalities when optimizing building standards.

Externalities justify cool roofs on **non-air conditioned buildings.**

Apply externalities also to cool pavements, vehicle roofs, even train roofs.

LAWRENCE BERKELEY NATIONAL LABORATORY PRESENTS:
SCIENCE AT THE THEATER

COOL CITIES, COOL PLANET

Arthur H. Rosenfeld, Ph.D.

Former Commissioner,
California Energy Commission

Distinguished Scientist Emeritus

Lawrence Berkeley National Lab

AHRosenfeld@lbl.gov
t: (510) 495-2227
http://ArtRosenfeld.org

Ronnen Levinson, Ph.D.

Staff Scientist and Acting Leader
Heat Island Group

Lawrence Berkeley National Lab

RMLevinson@lbl.gov
t: (510) 486-7494
http://CoolColors.lbl.gov

Melvin Pomerantz, Ph.D.

Staff Scientist
Heat Island Group

Lawrence Berkeley National Lab

M_Pomerantz@lbl.gov
t: (510) 486-4801

Resources on the web

- Art Rosenfeld's website
  - ArtRosenfeld.org
- Cool Colors Project
  - CoolColors.LBL.gov
- Heat Island Group
  - HeatIsland.LBL.gov
- Cool Communities Project
  - CoolCommunities.LBL.gov
- Roof Savings Calculator
  - RoofCalc.com
- White Roofs Alliance
  - WhiteRoofsAlliance.org
- Cool Roof Rating Council
  - CoolRoofs.org
- Cool California
  - CoolCalifornia.org
- EPA Heat Islands
  - epa.gov/heatisland
- Energy Star Cool Roofs
  - EnergyStar.gov